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Plasma Wave Observations During Electron Beam Experiments at High Altitudes

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Electron beam experiments on the nearly geosynchronous P78-2 satellite conducted in 1979 resulted in observations of electron distributions suggestive of electron heating. Plasma wave observations during these experiments indicated intense radiation at the local electron gyrofrequency. The amplitude of these waves depended upon beam parameters. During 50 eV beam operations, current levels of 10 μA produced strong emissions. Current levels of 1 μA and 100 μA did not. Sufficient power was in the observed emissions to explain the heated electron distributions observed during the experiments.

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PREFACE

This work was conducted with funds administered by the Naval Postgraduate School Research Council and NASA Lewis Research Center. The work at The Aerospace Corporation was supported by the U.S. Air Force Systems Command's Space Systems Division under Contract F04701-88-C-0089. The plasma wave data were obtained from the principal investigator, Dr. Harry Koons of Aerospace Corporation. The principal investigator for the electron gun, Mr. Herb Cohen, labored mightily to operate the experiment, and provided substantial help in recognizing and interpreting electron gun operating modes. Ms. Delia Donatelli did a substantial amount of work on the plasma wave data (unpublished) from which we have benefited. These data are from a series of experiments conducted with the unending support and patience of the AF/NASA personnel.

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I. INTRODUCTION

A. SATELLITE CHARGING

Satellite charging is the buildup of static electrical charge on the surface of satellites and has become an important issue in the use of satellite systems. Large negative potentials occur due to an imbalance between ambient electron and ion currents and currents generated by photoemission and secondary electrons. Spacecraft charging effects have been observed on several satellites over the past few years [DeForest,[1] Garrett,[2] Grard,[3] Olsen[4]]. The large negative potentials that have been induced on geosynchronous satellites have been linked to satellite failures and unexpected mode changes that have been observed periodically over the past several years. These anomalies can be directly attributed to spacecraft charging effects, which create arcing on the satellite surface, resulting in material breakdown and subsequent failure of the satellite. Motivated by the desire to control charging, experiments were conducted on Applied Technology Satellites 5 and 6 with electron and plasma sources [Olsen[4,5]] and on the P78-2 satellite using electron and ion sources [Olsen[6]]. The latter mission was part of the joint AF/NASA program on Spacecraft Charging at High Altitudes (SCATHA). Charging results from the electron beam experiments have been partially reported by Olsen[4] and Gussenoven et al.[7] Analysis of the particle spectra observed during some electron gun experiments suggested the possibility of electron heating in the near-satellite environment [Olsen[6]]. This motivated a desire to consider the plasma wave data taken during the electron beam experiments.

B. PLASMA WAVES AND ACTIVE EXPERIMENTS

An extensive data set on active experiments is emerging after ~15 years of research with electron beams in the ionosphere and magnetosphere. The first major series of electron beam emitting vehicles with wave data were the ECHO rockets, instrumented and launched by the University of

Minnesota. Winkler[8] reviewed the ECHO series and other pertinent experiments, noting the general nature of observed radiation patterns. ECHO I results were presented by Cartwright and Kellogg.[9] Particularly noteworthy were emissions at the local plasma frequency (or upper hybrid resonance frequency) and twice the gyrofrequency (e.g., Bernstein mode). Signals generated at the second gyroharmonic by the ECHO IV electron beam (8 to 40-keV, roughly 100 mA), were strong enough to be detected by ground receivers [Monson and Kellogg[10]].

An extensive set of rocket experiments have been conducted by Japanese experimenters. Kawashima et al.[11] reported on the seven flights to that point, with beam parameters and noteworthy results. Matsumoto et al.[12] reported on wave phenomena in the VLF range observed by the Japanese sounding rocket K-9M-41. A low energy electron beam was used to investigate the nonlinear wave and particle interactions in the ionospheric plasma. Triggered emissions at frequencies around the lower hybrid resonance frequency were found. Kawashima et al.[13] reported VLF waves excited by electron beam operations on the Japan-US tether rocket experiment CHARGE-2.

The French-Russian ARAKS experiments were sounding rocket payloads with 0.5 and 1.0 A beams at 15 and 27 keV [Gendrin[14]]. The experiments were conducted over the Kerguelen Islands at 100 to 200 km on 26 January 1975 and 15 February 1975. Cesium plasma sources (hollow cathodes) were included for current neutralization. These were nominally rated at 10 A plasma flux, which seems a curiously high current by American standards [Cambou et al.[15]]. The ARAKS experiments resulted in measurements of emissions at the plasma frequency and twice the gyrofrequency during both flights. Similar spectra had been noted during the ECHO flights [Lavergnat et al.[16]]. In the VLF frequency range, the principal result was the observation of waves which were most likely a resonance at the local lower hybrid resonance frequency, modified by the presence of the cesium plasma created by the hollow cathodes [Dechambre et al.[17]].

Stimulated plasma waves in the VLF range are reported by Akai[18] and Kawashima et al.[19,20] for experiments on the Japanese satellite, Jikiken

(EXOS-B). EXOS-B was in a relatively low orbit (compared to SCATHA), but at similar L region, and hence in similar plasma environments. Electron gun experiments were conducted to study wave excitation phenomena (both linear and nonlinear) due to beam-plasma interactions, and to control satellite potential by electron beam emission. The electron gun current was stepped from 0.25 - 1.0 mA in 0.25 mA increments. The gun voltage was stepped from 100 to 200 V in 25 V increments. The plasma waves were classified by type based on the L region in which they are observed. Waves at the electron gyrofrequency and its harmonics, the upper hybrid resonance frequency, and the plasma frequency were observed.

Experiments on ISEE-1 used beam currents of 10 to 60 μA and beam energies of 0 to 40 eV. This is comparable to SCATHA data we will present. Lebreton et al.[21] reported the enhancement of the electric wave spectrum by the injection of an electron beam on ISEE-1. No clearly identified resonances were reported.

Koons and Cohen[22] reported some of the electrical discharges stimulated by an electron beam on SCATHA. Correlation between a change in gun parameters and a change to the spectrum was noted. Electrostatic emissions above the electron gyrofrequency were detected on the electric antenna. The work presented in this report extends these results.

Plasma waves at the plasma frequency and at the electron gyrofrequency generated in the laboratory are discussed by Bernstein et al.[23] Electron beam-plasma interactions are of interest, but tend to deal with the beam-plasma discharge which involves a neutral gas background.

These are numerous reports in the literature of naturally occurring emissions at or near the electron gyrofrequency [e.g. Koons and Edgar[24]]. Although the dispersion relation for electron gyrofrequency harmonic waves does not have a solution at exactly the gyrofrequency, Koons and Edgar[24] report detection of emissions by the VLF receiver on SCATHA at and just above the local electron gyrofrequency. They concluded that present theories could not account for the waves that were the subject of their report.

This report will present the plasma wave data taken over a day-long period when active experiments with the SCATHA electron gun were being conducted. Identification of plasma waves stimulated by the electron beam at or near the electron gyrofrequency was the major focus of this investigation.

II. THE SCATHA PROGRAM

A. SCATHA SATELLITE

The Air Force P78-2 satellite (Figure 1), known as SCATHA for Spacecraft Charging at High Altitude, was launched in January 1979 to study causes and dynamics of spacecraft charging processes at geosynchronous orbit. The satellite was launched into a nearly geosychronous orbit with a period of 23.5 h at an apogee of 7.3 Re and a perigee of 5.8 Re. The satellite is cylindrical in shape measuring approximately 1.75 m long and 1.75 m wide. It is spin stabilized at about 1 rpm with the spin axis in the plane of the orbit and perpendicular to a line between the earth and sun. Most of the instruments are mounted in the belly band of the cylinder, while solar cells cover most of the remaining part (Figure 1). The relative locations of the electron gun (SC4-1), magnetic loop (SC1-4) and long electric antenna (SC10-1,-2) are particularly pertinent. Also included in the scientific package were various instruments to measure the potentials existing near the spacecraft and to detect wave and particle emissions. The scientific instruments are described in detail by Fennell.[25] The electron gun experiment is described below.

B. ELECTRON GUN

The electron beam system (SC4-1) on SCATHA was designed to emit a stream of electrons over a range of beam currents and energies. The electron beam emitter is basically a power triode tube consisting of an indirectly heated cathode, control grid, focusing assembly, and an exit anode at satellite ground. The beam could be operated at currents ranging from 1 μA to 13 mA, and voltage settings from 50 V to 3.0 kV. Duty cycles of 6.25% and 100% were available. The higher current settings were not used due to power restrictions and operational constraints. Currents above 1 mA were not routinely used due to the detrimental effect the beam had on other instrumentation [Gussenoven et al.[26]]. Specifically, severe arcing was noted on the satellite surfaces and resulted in the failure of two of

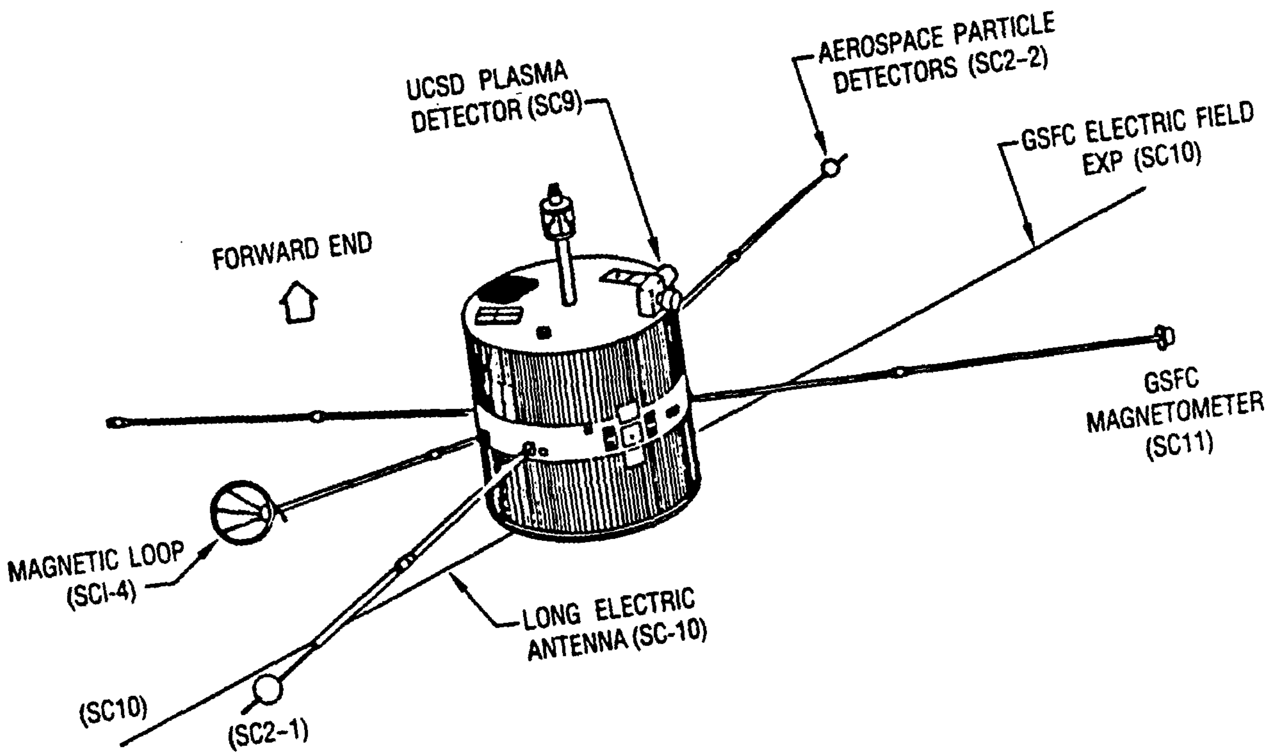

Figure 1. SCATHA Space Vehicle (P78-2). The electron gun (SC4-1) is on the belly band, on the hidden side of the vehicle.

the experiments on 29 March 1979 [Koons and Cohen[22]]. The experiments reported below utilized the 10 and 100 μA settings at 50 V.

C. DETECTORS

The SC-1 experiment measured VLF and HF emissions and provided the broadband data presented in the spectrograms. The SC-1 experiment employed two antennas, one for electric field measurements and one for magnetic field measurements. The electric antenna was the 100 m tip-to-tip dipole used by the electric field (SC10) experiment. The two halves were extended perpendicular to the spin axis. The inner 30 m of each 50 m segment was coated with Kapton insulation. The magnetic antenna was an electrostatically shielded air core loop with an effective 575 m^2 cross section at 1.6 kHz mounted on a 2 m boom off the belly band of the satellite. These antennas were connected to both wide-band and narrow-band receivers. The wide-band channel could be operated with nominal frequency ranges of 0 to 3 and 0 to 5 kHz (depending on telemetry mode). The narrow-band receiver had eight channels, with center frequencies of 0.4, 1.3, 2.3, 3.0, 10.5, 30,0, 100.0, and 300 kHz, respectively. These narrow-band channels each have relative bandwidths of ±7.5%. The instrument was operated with the receivers connected to the electric and magnetic antenna for alternating 16-s intervals. The sensitivity of the magnetic receiver was 3×10^{-6} gamma/$Hz^{1/2}$ at 1.3 kHz. The electric field receiver sensitivity was 5×10^{-7} V/$(m\text{-}Hz)^{1/2}$ at 1.3 kHz and 10^{-7} V/$(m\text{-}Hz)^{1/2}$ at 10.5 kHz. Each receiver had a 60 dB dynamic range.

Magnetic field data are from the GSFC magnetometer (SC11). The triaxial fluxgate magnetometer was mounted on a 4 m boom. Four vector measurements per second were provided, with 0.3 gamma resolution. The magnetic field data were perturbed by local satellite currents, which introduced an error of up to 1 gamma in the absolute magnetic field measurement [Koons and Edgar[27], B. G. Ledley*].

*Private communication, November 1987.

III. OBSERVATIONS

The observations presented here are the result of a survey of all the available plasma wave data taken during the 1979 electron gun experiments. The main feature of the data, which immediately became apparent, was that most electron gun operations resulted in monochromatic emissions at a wide range of frequencies. These emissions were typically constant in frequency with time, varying when the gun current or voltage was changed. The origin of these spectral lines has not been identified, though a reasonable candidate might be a voltage controlled oscillator (VCO) somewhere in the gun. Hence, the majority of the observations do not appear to correspond to interactions between the electron beam and local plasma.

The one major exception to this typical behavior occurred on 20 July 1979 (day 201). A number of a low power (50 V, 10 to 100 μA) experiments were being conducted in daylight, at various local times. Monochromatic signals were found which could be attributed to local plasma interactions. These observations are fortuitously associated with electron observations which may be taken as indicating electron heating [Olsen[6]]. This was a magnetically disturbed day with Kp=4 for the 2100-2400 period. The satellite was in the dusk bulge at 7.5 RE, L=8.1, and magnetic latitude of 6 deg.

Experiments conducted with the electron gun on 20 July 1979 (day 201), as presented here, were part of a sequence of experiments which resulted in "real-time" observations of enhanced electron flux above the beam energy [Olsen[6]]. Hence, the cycling of the gun modes was oriented towards understanding the UCSD particle detector response.

Figure 2 summarizes the 400 Hz to 3.0 kHz electric and magnetic filter data from the SC-1 experiment. The gun current is indicated within the top panels (3.0 kHz). The lowest value is 0 μA (off); intermediate values are 10 μA. The two small peaks at 2302 and 2322 are the 100 μA excursions. The gun on periods are most clearly noticeable in the magnetic channels

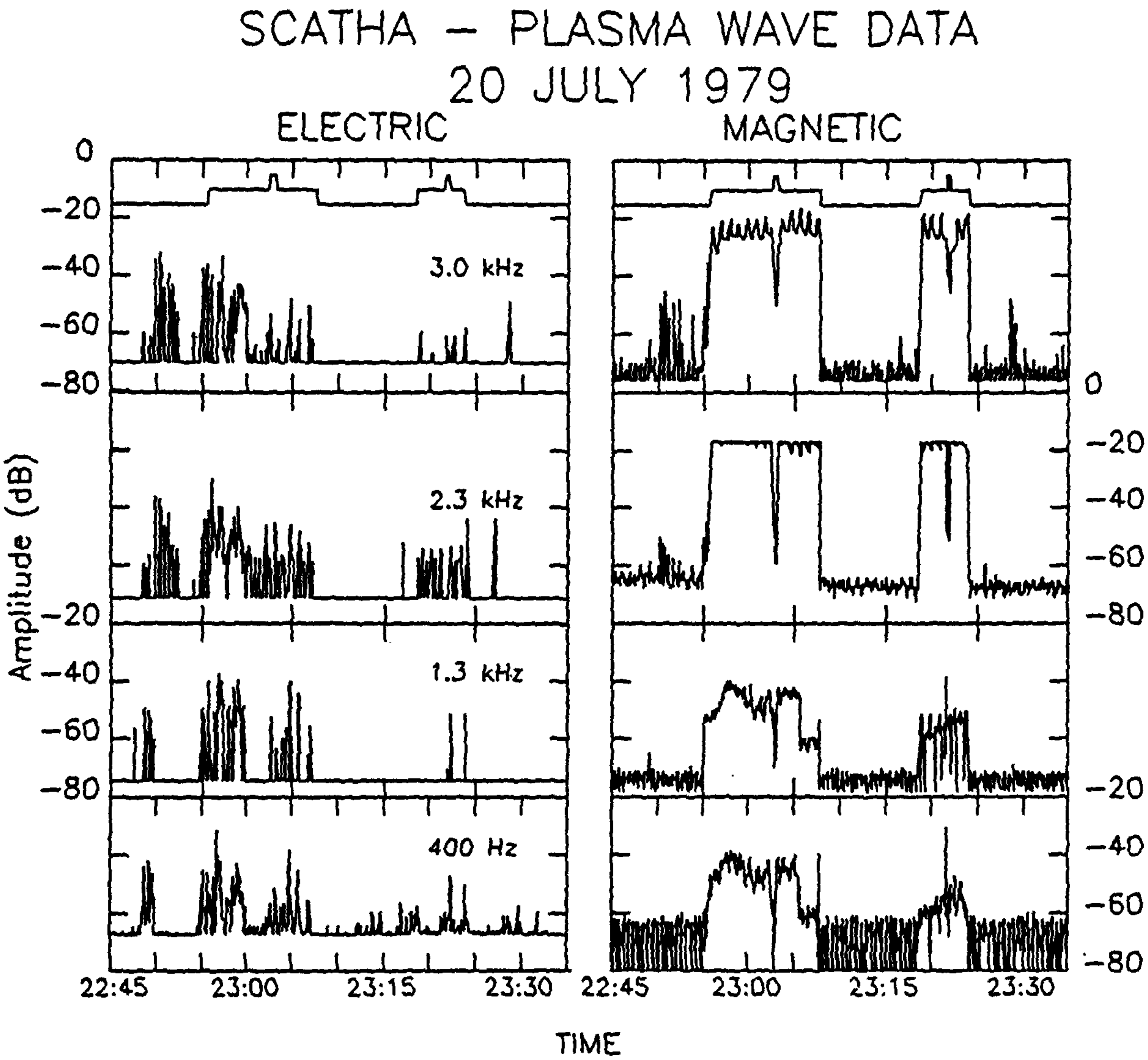

Figure 2. Narrowband Electric and Magnetic Receiver Data for 20 July 1979

(right hand side). The most obvious conclusion which appears is that the electron gun causes a 20 to 30 dB jump in the magnetic receiver output, with a smaller (~10 dB) increase in the electric channels. No response was seen in the four higher frequency electric channels (10 to 300 kHz). Further consideration of the figure reveals a number of intriguing points. Gun operations at 10 μA cause the 2.3 kHz channel to saturate, with less extreme increases at the other frequencies. There is a spin modulation which is most obvious in the 3.0 kHz magnetic channel. This point will be addressed later. Increasing the gun current to 100 μA causes a substantial decrease in the stimulated wave response.

The wide-band data provide the complementary frequency spectra needed to further interpret this plot. Figure 3 shows typical plasma wave data in spectrogram form for this time period. A spectrogram is a grey scale presentation of the plasma wave data as a function of time and frequency. The vertical axis is frequency from 0 to 3 kHz. The horizontal axis is time. Amplitude of the signal in is proportional to the intensity. High amplitude is plotted as black, low amplitude as white, and intermediate values as various shades of grey. For example, intense signals can be seen at 0.7 and 2.1 kHz in the magnetic antenna data, denoted by B in Figure 3. A less intense signal is found at 1.4 kHz. These interference lines are caused by a 700 Hz tuning fork oscillator that is part of another satellite experiment. These interference lines have been identified previously and have been seen in most data. The receiver is cycled between the electric (denoted by E in Figure 3) and magnetic antennae (denoted by B) every 16 s. Naturally occurring electrostatic electron cyclotron (f_{ce}) waves (the short vertical striations between 2250 and 2252) are observed from about 2.5 to 2.7 kHz. They are identified by the fact that they occur at the unique frequency, f_{ce}, as calculated from the magnetic field data. From 22:48:30 to 22:50:00, low frequency (less than 300 Hz) signals can be seen in the electric field data. These appear to be naturally occurring signals since they have finite bandwidth. They have not been identified, however. (Note: crosstalk-electrostatic emissions are often observed in the

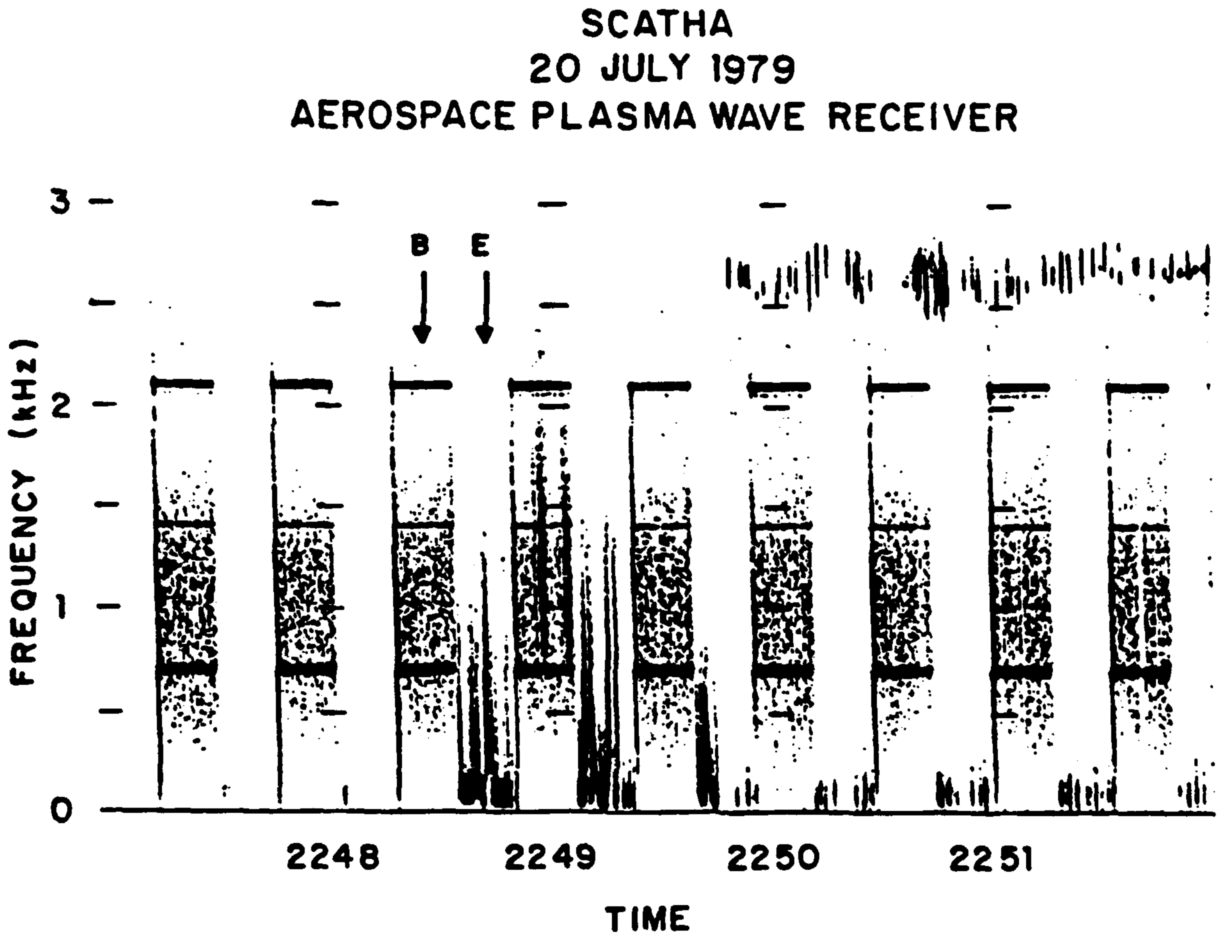

Figure 3. Spectrogram Showing Typical Plasma Wave Data with Naturally Occurring Electron Cyclotron Waves

magnetic receiver data.) It is likely that the observed signals are electrostatic [Koons and Edgar,[24] Koons*]. A summary of the SC4-1 commands is listed in Table 1.

Table 1. A Summary of SC4-1 Commands on 20 July 1079 (Day 201)

TIME	SC4-1 COMMAND
22:53:40	Initialize and Off
22:54:54	System On
22:55:00	Beam On
22:55:37	Beam Current to 10 μA
23:02:28	Beam Current to 100 μA
23:03:15	Beam Current to 10 μA
23:07:41	Beam Off
23:18:31	Beam On 10 μA
23:21:58	Beam Current to 100 μA
23:23:48	Beam Off
23:26:03	Initialize and Off

All the remaining data from this operation are ordered by f_{ce}, and we use the measured magnetic field strength from the fluxgate magnetometer to compute the plot f_{ce} over the spectra. The gyrofrequency was computed at 2-s intervals from the magnetic field strength and plotted on the spectrogram (small dots). Evidence of the magnetic activity can be seen early in the 2241-2330 period in the fluctuation of the magnetic field strength. The naturally occurring electron cyclotron waves (f_{ce}) which begin in Figure 3 at 2250 continue on the next spectrogram (Figure 4). The naturally occurring waves from 2252 to 2254 (faint vertical stripes) are neatly

*Private communication, November 1987.

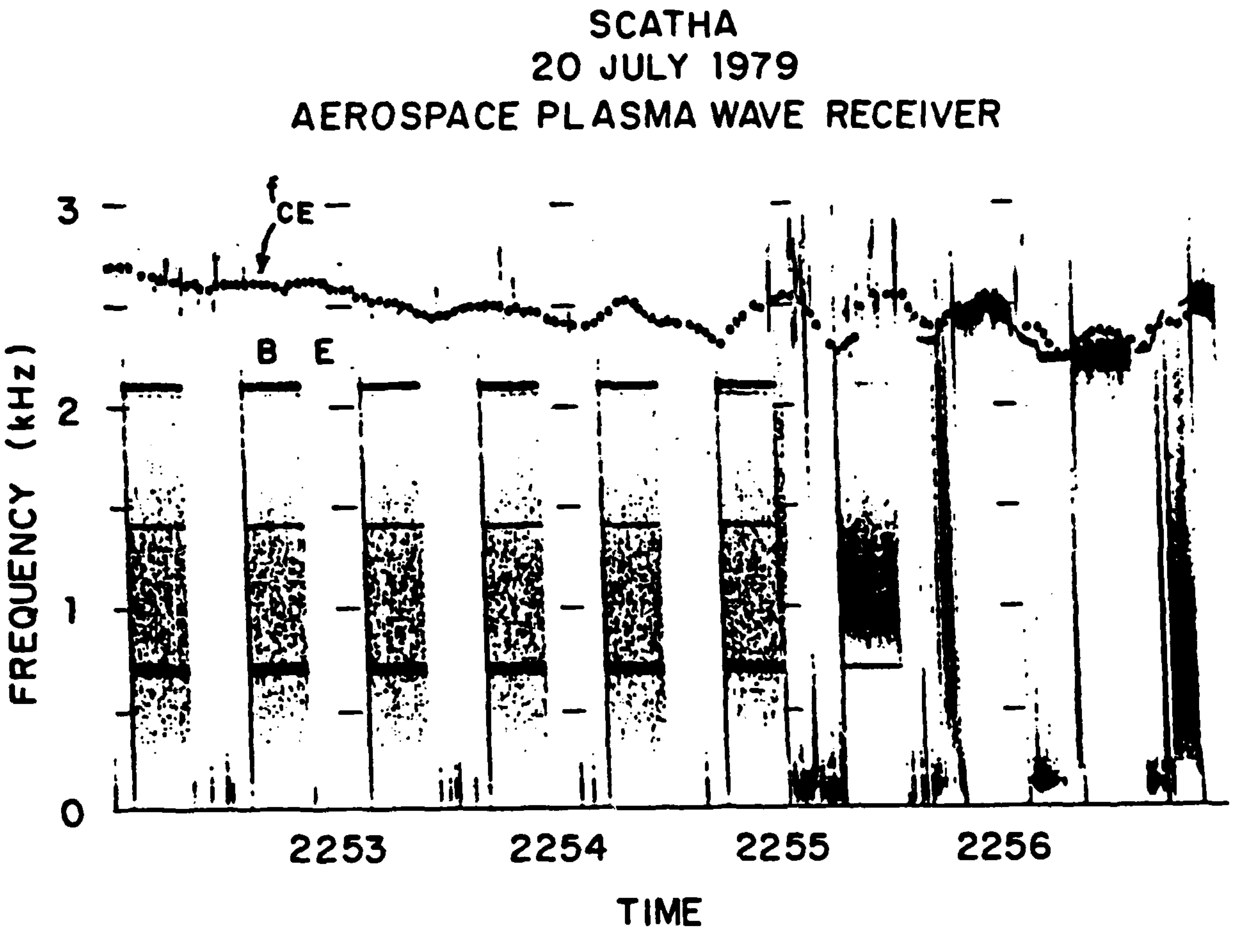

Figure 4. Naturally Occurring Electron Cyclotron Waves. The electron cyclotron frequency is overplotted with dots. The effect of the electron gun being turned on is seen at 22:55:00.

matched to the calculated time-varying gyrofrequency overplotted. These signals are similar in appearance to those which were induced by the electron gun operations.

At 22:53:40 the electron gun system was initialized. It was powered up at 22:54:54. At 22:55:00 the electron gun was turned on. A prompt, if muddled, effect can be seen on the plasma wave data (Figure 4). The tuning-fork-related interference lines are masked, and a strong broadband signal can be seen in the magnetic field spectrum. At 22:55:37 the electron beam was energized at a current level of 10 μA and 50 eV. The gun was operated continuously in this mode until 23:02:28, when the beam current was increased to 100 μA.

A monochromatic signal, similar to the f_{ce} wave, was observed in the 10 μA mode. The intense, monochromatic signal above 2 kHz varied in frequency from about 2400 to 2600 Hz, as seen in the latter period of Figure 4. This signal is modulated in frequency at the satellite spin period of 59 s, has a very narrow bandwidth, and appears monochromatic in the electric data to within receiver resolution. For example, line plots showed a monochromatic signal near 2400 Hz at 2256:00. The gyrofrequency calculated from the magnetic field strength for this time was 2385 Hz. In the early part of the period after the electron gun was first turned on (22:55:00 to 22:57:00), the signal was at or near the electron gyrofrequency, mimicking the naturally occurring waves. This is apparently the signal which drives the 2.3 kHz magnetic channel to saturation (Figure 2).

Figure 5 shows that significant differences between f_{ce} and the signal frequency begin to occur by 22:58:00. In particular, the signal frequency drops substantially below the gyrofrequency (at 22:59:00). This is significant because it suggests the signal is not an electron cyclotron wave. The signal continues for as long as the electron gun is operated in the 10 μA mode. The fluctuation in the frequency of the signal is approximately sinusoidal and is repeatable over several periods. This period is close to or equal to the satellite spin period. Details of the fluctuation in frequency include a "knee" in the electric field spectrogram (at

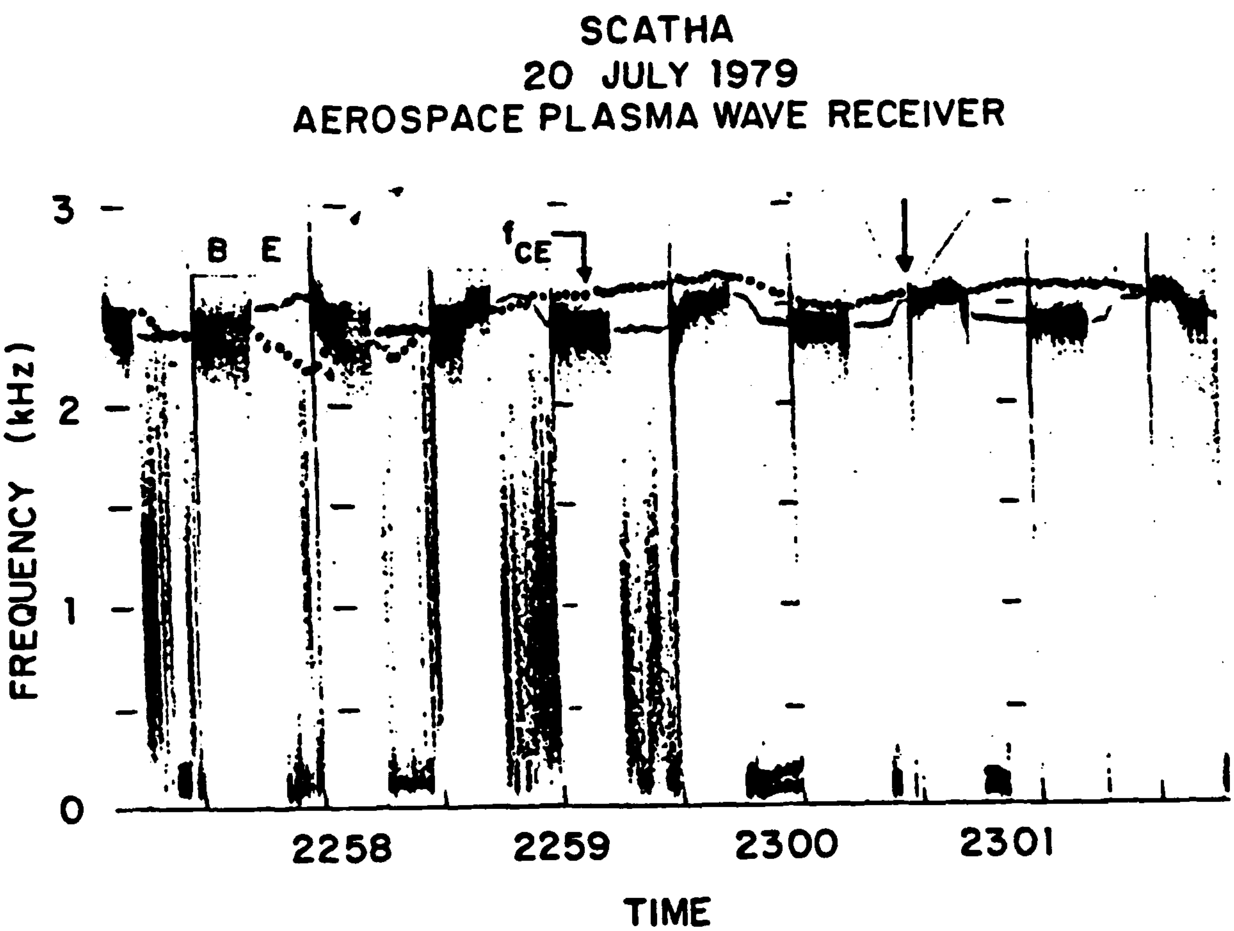

Figure 5. Variations in the Stimulated Wave Frequency Eventually Drop Below the Nominal Gyrofrequency

23:00:30, arrow on top right in Figure 5). This is a distinguishable characteristic of the signal and appears in the same general position on the waveform throughout this period.

Significant changes in the plasma wave data result from changes to the gun parameters. From 23:02:28 to 23:03:15, the gun beam current was increased to 100 μA. The VLF data with the gun on at 100 μA appeared similar to the data with the electron beam off. The strong interference lines at 700 and 2100 Hz reappear in the magnetic channel. Close examination of the data indicated that some of the sporadic naturally occurring electron cyclotron waves were present. The intense monochromatic signal seen at 10 μA beam current disappeared. The decrease in the AGC controlled wideband response is confirmed by the filter data shown in Figure 2.

At 23:03:15 the beam current was reduced to 10 μA and the VLF characteristics returned to those previously observed at 10 μA beam current (i.e., the 2.4-2.7 kHz signal was again present). The system remained in this configuration until 23:07:41, when the electron beam was turned off. The VLF characteristics reverted to those observed prior to the gun operations (prior to 22:55:00). The 700, 1400, and 2100 Hz interference lines returned. For the next 10 to 12 min the electric spectra revealed no obvious signals, and the magnetic antenna showed only the tuning fork lines and receiver noise.

The repeatability of the effects of the electron gun operations were emphasized by repetition of the sequence. At 23:18:31 the electron beam was again turned on at 10 μA beam current. The VLF data resumed the behavior shown previously. The signal oscillating between 2400 and 2600 Hz returned and the low frequency signal (100 to 200 Hz) became more intense. From 23:21:34 to 23:21:58 the beam current was increased to 100 μA, and again the 2400-2600 Hz signal disappeared and the interference lines reappeared in the magnetic data. At 23:21:58 the beam current was reduced to 10 μA and the VLF data regained their familiar character. At 23:23:48 the electron beam was turned off and the 700, 1400, and 2100 Hz interference lines could again be seen in the magnetic receiver data. Sporadic electron gyrofrequency emissions were present also.

IV. DISCUSSION

The 2.4 to 2.7 kHz signal observed during the 10 μA mode of operation is strongly linked in frequency characteristics to electron cyclotron waves--near, but not at the natural cyclotron frequency. This signal is the dominant effect that was seen in the VLF data during the gun operation, and we attempt here to explain the source of this apparently stimulated electron cyclotron wave. The apparent broadness of the signal in the magnetic field data is a result of the AGC control on the satellite and the processing system. Although this signal appears to have a finite bandwidth, it is most likely the same monochromatic signal observed by the electric antenna. The relatively constant amplitude suggests that the satellite itself is the source of the signal. Since the signal is only visible at 10 μA beam current, there are apparently beam-plasma effects which determine the propagation of the signal to the electric and magnetic antennas through the ambient plasma. Theory holds that there should be no signals below the gyrofrequency due to dispersion. The fact that the oscillation drops below the calculated gyrofrequency is disturbing. Since the signal is close to f_{ce}, we pursued the idea that there was something causing the magnetic field strength near the satellite to vary. One thing that might perturb the satellite magnetic field is the solar array current. Figure 6 shows the solar array current, I_{sa}, plotted with the frequency of plasma wave oscillation seen on 20 July 1979. Also plotted is the amplitude of the signal in the 3 kHz magnetic channel. The solar array current is obviously modulated at the satellite spin period. This is a result of shadowing of the solar cells as the booms pass between the satellite and the sun. The similarity of the shape of the solar array current to the variation in the SC-1 signal frequency and amplitude is strong. We suggest that the solar array current causes a perturbation to the total magnetic field. This field is largely balanced out by design, but is nonzero. The perturbation field, or satellite magnetic moment, will vary with the solar array current, I_{sa}. The perturbation in the magnetic field strength near the satellite then results in a slight change in the electron gyrofrequency ($\Delta B \propto \Delta I_{sa}$, $\Delta f_{ce} \propto \Delta B$).

The question of where to evaluate the magnetic field is raised at this point. The two possibilities are the source, or generation region, for the waves, and the antenna, or reception region. Note in Figure 5 that there is no shift in the frequency of the received signal when the antennas are switched. This implies that either both the electric and magnetic loop antenna are coupling at the same location, which seems unlikely, or they are responding to a source at a constant frequency. This source region would be the beam-plasma interaction region, which is probably quite close to the satellite (e.g., within 1 m).

The measured magnetic field is obtained from sensors at the end of a 4 m boom. The value of the magnetic field at the magnetometer is known to have an error of a few gamma due to satellite generated fields [B. Ledley*]. Hence, a perturbation field of 10 gamma near the satellite surface, dropping to a few gamma at 4 m, is consistent with a fluctuation in f_{ce} of 280 Hz. A net, unbalanced, current fluctuation of 0.1 to 1.0 A should be able to produce a field of 10 gamma (nano-Tesla), dropping as $1/r^3$ away from the solar array. This could account for the cyclotron emission appearing below the gyrofrequency. The oscillation varies in frequency by only a few hundred hertz. The magnetic intensity would only have to produce this change, well within our estimates. Note again that the modulation of the solar array current closely matches the shape of the modulation of the plasma wave data (Figure 6). The modulation of the 3 kHz data can be understood as movement of the signal frequency in and out of the passband for that channel.

We observed similar behavior over several operational periods on this day. No other clear examples of f_{ce} related emissions have yet been found on other days. A relationship between the operation of the electron gun and the plasma wave spectra is consistently found. The gun operation either couples satellite (electron gun) generated interference to the

*Private communication, November 1987.

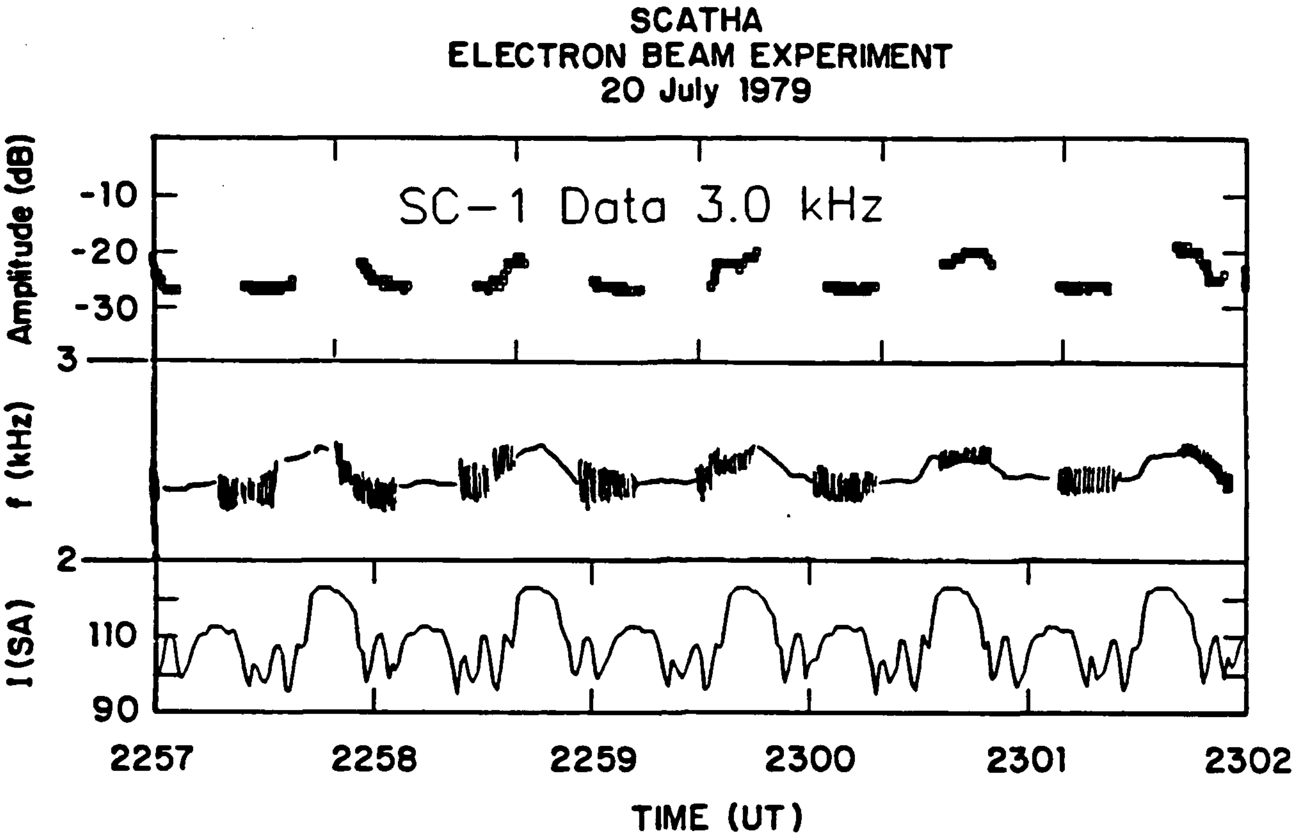

Figure 6. (Top) Signal from 3.0 kHz Channel, Magnetic Antenna; (Middle) Frequency of Intense Signal in Wideband Data; (Bottom) Solar Array Current, as Modulated by the Satellite Spin.

plasma wave experiments or the beam interacts with the plasma near the satellite in a characteristic, repeatable way. This latter possibility is suggested by the beam current dependencc and discounted by the relationship to the electron cyclotron frequency. Given the limitations to the accuracy of the sensors (especially the magnetometer) and their location with respect to the satellite, the observation of the stimulated plasma wave below the gyrofrequency can be adequately explained. The mechanism for the generation of the signal has not been pursued, but observations suggest that a plasma wave was stimulated at the electron gyrofrequency due to operation of the electron gun. This would be consistent with standard calculations of beam-generated waves [Chen[28]].

V. CONCLUSIONS

On Day 200 the electron gun stimulated an emission at the local electron gyrofrequency when operated at 10 μA, 50 V. This signal resembled naturally occurring f_{ce} waves during the same period. Fluctuations in the frequency of the signal correlated with satellite spin and solar array current variations, and show that the signal is a result of interactions between the electron beam and local plasma. This is consistent with inferences of ambient electron heating due to the beam [Olsen[6]]. The waves were clearly affected by the selected current level, indicating the traditional dependence on N_{beam} vs. $N_{ambient}$. As a result of this work, operations were scheduled for the final orbits of ISEE-1 in summer, 1987. The electron gun was operated from the magnetopause into perigee. Studies of these data are just beginning, but should resolve the f_{ce} dependence found here, with the advantage of higher frequency range (e.g., up to the plasma frequency).

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LABORATORY OPERATIONS

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Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, chemical dynamics, environmental chemistry, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed chemical and excimer laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, sensor out-of-field-of-view rejection, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, microelectronics applications, communication protocols, and computer security.

Electronics Research Laboratory: Microelectronics, solid-state device physics, compound semiconductors, radiation hardening; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; microwave semiconductor devices, microwave/millimeter wave measurements, diagnostics and radiometry, microwave/millimeter wave thermionic devices; atomic time and frequency standards; antennas, rf systems, electromagnetic propagation phenomena, space communication systems.

Materials Sciences Laboratory: Development of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.